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Technological Impact on Future Air Force Personnel & Training: Distributed Collaborative Decision-Making, Volume I. Final Report

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NOTICE

This report contains three volumes. Volume I, this volume, is the final report of a survey of distributed collaborative decision-making topics relevant to future Air Force personnel and training issues. Volume II contains pertinent non-copyrighted citations extracted from government databases, and Volume III contains pertinent copyrighted citations extracted from commercial databases. A table of contents for the three-volume set may be found in Volume I.

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13. ABSTRACT ***(Maximum 200 Words)***
This Review and Analysis examined the science of decision-making to determine how the Air Force could exploit this discipline in the future battlespace and military operations. The most important messages of this *Review & Analysis* for the Air Force are these:

- Research on the differences between group and individual decision-making indicates that the biggest benefit of collaborative group decision-making is the group's increased cognitive resources, compared to that of a single individual.
- The greatest detriment to collaborative distributed decision-making is that we must rely on technology rather than face-to-face interactions, and subtleties of human communication may be lost.
- The best predictor of good decision-making is the experience of the decision-maker, the implication being that training for decision-making is paramount.
- While personality and other selection indices of the future may have better success, current tools do not offer a great deal of information about who will be a good decision-maker in general.
- All the military services are engaged in research into what variables are important in a group decision-making program.

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FOREWORD

This report documents a *Review & Analysis* of *Distributed, Collaborative Decision-Making*, as it affects future Air Force personnel and training issues. The task was performed by the Crew System Ergonomics Information Analysis Center (CSERIAC) for Armstrong Laboratory, Cognition and Performance Division, Force Planning and Management Technology Branch (AL/HRCF). It was conducted under Department of Defense (DoD) Contract Number SPO900-94-D-0001, and the CSERIAC subscription account number 891AZ2701 93704-27. The CSERIAC Director during this period was Mr. Donald A. Dreesbach. The primary human factors analyst and author was Barbara Palmer, who was assisted by human factors analysts Joyce A. Cameron and Jennifer I. Soest. Mark A. Cummings assisted with document preparation and distribution. These analysts worked under the direction of the CSERIAC Project Manager and Senior Technical Analyst, Frank C. Gentner. Joyce Cameron and Frank Gentner developed the briefing in Attachment A, based on the report and other related materials.

EXECUTIVE SUMMARY

The future battlefield will be characterized by complex and dense information flows, with operators and decision-makers at times in close proximity, and in other situations, distant from one another. Decisions will be made by groups of people often geographically separated from one another. This *Review & Analysis* describes how such decisions are made, and presents research regarding how good group decision-makers can be selected and trained.

As the Air Force prepares for the decades ahead, decisions need to be made now to select and prepare tomorrow's decision-makers. This document reviews planning documents of the Air Force and the Department of Defense, and scientific and technical reports regarding the scientific study of decision-making, to paint a picture of the types of tasks future Air Force decision-makers will perform, and how they will make decisions.

This *Review & Analysis* examined how the Air Force could exploit the scientific findings regarding decision-making as it lays plans for the future battlespace and other military operations. The most important messages of this *Review & Analysis* for the Air Force are the following:

- Research on the differences between group and individual decision-making indicates that the biggest benefit of collaborative group activity is the group's increased cognitive resources, compared to that of a single individual.
- The greatest detriment to collaborative distributed decision-making is that we must rely on technology rather than face-to-face interactions, and subtleties of human communication may be lost.
- The best predictor of good decision-making is the experience of the decision-maker, the implication being that training for decision-making is paramount.
- While future indices of personality and other selection variables may have better success, current tools do not offer a great deal of information about who, in the general sense, will be a good decision-maker.
- All the military services are engaged in research into what variables are important in a group decision-making training program.
- A group decision-making training program is outlined, which focuses on communication skills, situation awareness, and decision-making skills.

1.0 INTRODUCTION

This *Review & Analysis* focuses on concepts involved in collaborative distributed decision-making. Also covered will be factors that research has shown to contribute to the success of a group's decision-making processes. Before we address some of these decision-making topics, a discussion of the elements of the future battlespace and some of its communication pathways may help establish a context within which this research will be relevant.

1.1 DECISION-MAKING IN THE CONTEXT OF THE FUTURE BATTLEFIELD

As we look at various views of the future battlefield, it will be clear why the Air Force is concerned about effective distributed collaborative decision-making. The future battlespace is painted for us in detail by joint service and Air Force vision documents such as *Air Force 2025* (Air University, Air Education and Training Command, 1996), *Joint Vision 2010* (Chairman of the Joint Chiefs of Staff, 1997), and the *Advanced Battlespace Information System (ABIS) Task Force Report* (Jones & Cebrowski, 1996). Main themes are that joint forces will work in even closer coordination and that decisions will be made in geographic locations distant from battle. The emphasis on groupwork and the geographical distance between decision-makers and the scene of action provides the motivation for this *Review & Analysis* on distributed collaborative decision-making. The critical nature of the decisions made by these groups is the key to battlespace dominance. No matter which view of the future battlespace turns out to be most accurate, all views of the future battlespace make it clear that this will be an information-age military. Superior weapons systems will no longer be sufficient. Those who can control the flow of information will have a certain advantage.

As with all complex decisions, decisions in the future battlefield will be heavily information-based. Information gathered from satellites, AWACS, and UAVs will flow to ground stations, tanks, and aircraft. Battles will be waged in a manner unlike any other time, and will be characterized by distributed decision-making and geographically disparate personnel. The authors of *Air Force 2025* (Air University, Air Education and Training Command, 1996) indicate that future battles may not be about the capture of land; rather they may be more space- and cyberspace-focused. Satellites and space-based sensors will be important, as will multi-function uninhabited air vehicles and space planes (transatmospheric vehicles). Joint operations will involve air, land, and naval cooperation. Information about the location of friendly forces, enemy forces, weather, logistics, and terrain data must be gathered, stored, channeled through a common operating environment, made available to decision-makers as needed, and accompanied by intelligent agents whose work it will be to minimize the information-processing burden of the user. The discipline of human factors will also be necessary in the creation of this interface between the information space and the user. This huge volume of information will be presented in a useable way to the decision-maker via information fusion, groupware, and virtual reality techniques. The mass of information gathered in the future battlespace will be enormous, and intelligent agents (software such as decision aids) will be needed to help refine the users' queries so that the right information can be delivered at the right time without overburdening the user.

Before a discussion of the discipline of decision-making, an example of a future war room will help put the topic of collaborative distributed decision-making in a relevant context for Air Force personnel strategists. By the year 2025, a virtual reality, holographic representation of a battle scene will be available to the Commander-in-Chief and others engaged in battleground decision-making. Weapons sensors and surveillance equipment will feed information in near real-time through the information grid, so that it will be available on an as-needed basis to military planners. In this vision, the distributed and collaborative nature of future military decision-making is clear.

*Air Force 2025 (*Air University, Air Education and Training Command, 1996) describes the future Commander in Chief (CINC)'s battle management operations center as an air operations center. The Commander in Chief and the Joint Force Air Component Commander (JFACC) will have a God's eye view of the battlespace made available through a highly sophisticated information processing network. The entire battlespace can be viewed, or the commander can zoom to a specific location, in a manner similar to that viewed in Figure 1, a holographic war room. This technology will allow monitoring and engagement through the area of responsibility, down to a specific target, allowing the JFACC to interact with the holographic depiction, controlling the engagement and monitoring the battle progress in near real time.

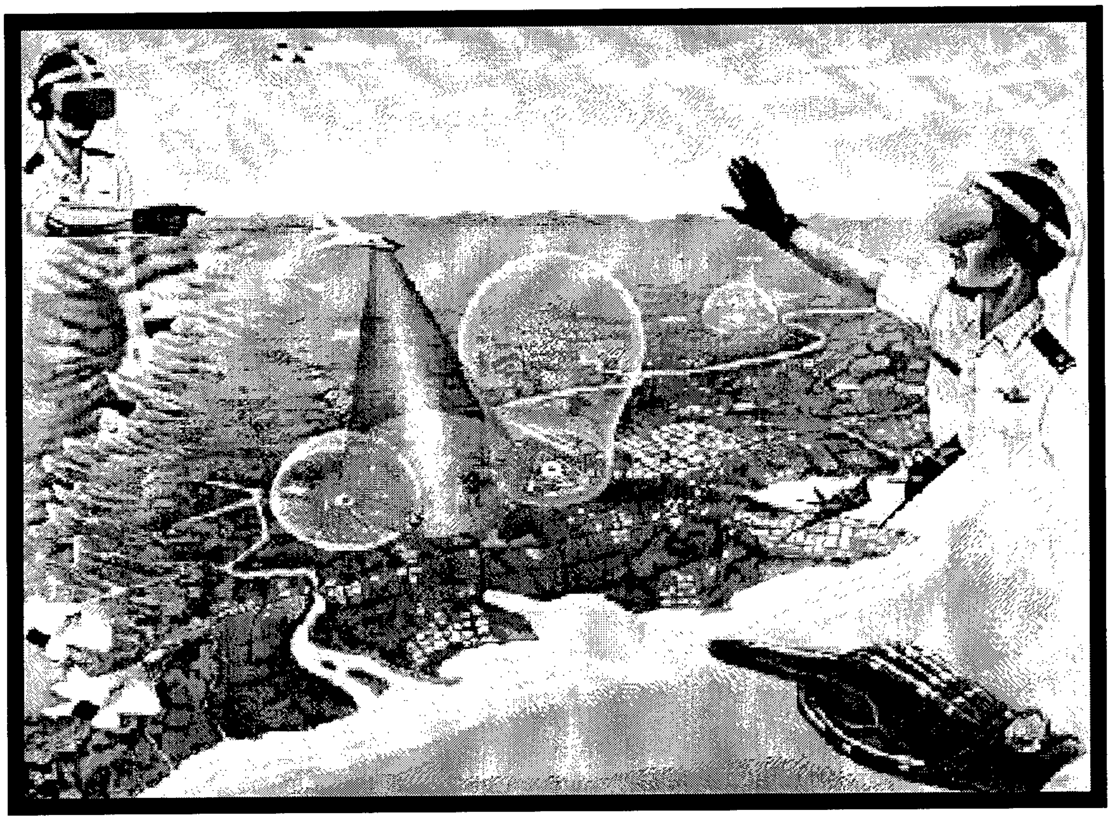

Figure 1. Holographic warroom of the future.
Source: http://www.afit.af.mil/Schools/PA/gall3.htm, **courtesy of Gene Lehman, Air Force Institute of Technology (AFIT/LSEC).**

The battle command center will allow real-time centralized control. Very high-speed computers will show battle simulations, forecast outcomes in accelerated time modes, and assess battle damage. Laser and microwave weapons will operate at the speed of light. Different courses of action will be evaluated via accelerated simulations. The capabilities and doctrines of enemy forces will be simulated through knowledge-based artificial intelligence software and the JFACC can mix weapons and weapons effects. A series of options can be simulated in this war room, and a course of action chosen. The commander then can send orders to the individual weapons systems for execution. All the systems will provide feedback, ensuring rapid retargeting so that the CINC's and the JFACC's objectives are met.

1.2. PURPOSE

Consider the downing of an Iranian airliner by the USS Vincennes, the Three Mile Island nuclear reactor incident, and the recent crash of an airliner in Colombia, and the catastrophic consequences of human error are clear. The complexities of modern technology and political situations place unprecedented demands on the human operator. As technological sophistication increases, decision-making will become even more complex (Salas & Cannon-Bowers, 1996). Several trends in today's world dictate the need for scientists to make advances in understanding, developing training, and supporting effective decision-making. Trends such as advancing technology, the complexity of decision environments, and the increasing cost of decision errors make it evident that this research is needed (Cannon-Bowers, Salas, & Pruitt, 1996). As Norman (1993) pointed out, people are facing more cognitively demanding tasks at work and play, and the consequences of poor or ineffective performance are becoming more costly, in terms of money and loss of life. Aviation accidents, military mishaps, and industrial incidents are often caused by human error (Cook & Woods, in press). Fortunately, there has been a resurgence of activity during the last ten years on the topic of decision-making, especially in the context of real, complex, time-compressed, stressful settings. This paper will focus for the most part on the *decision-maker* rather than on the process of decision-making, but we must first examine the topics being studied under the aegis of *decision-making* so that we are aware of the tasks and constraints facing decision-makers. Some very brief mention of the theoretical thrusts will lead to a discussion of the state of research into how to select good decision-makers and how to train for effective decision-making.

The purpose of this *Review & Analysis* is to introduce topics in the realm of decision-making and to point out their relevance to communications that are likely in the future battlespace. Examples of current group decision-making training programs are presented, and recommendations for future research and development are made. Implications for future AF personnel and training issues are indicated.

1.3 DEFINITIONS

The topic of this *Review & Analysis* is *Distributed Collaborative Decision-Making*. A definition of some important terms is in order; the terms involved, decision-making, distributed, and collaborative, will be defined. Later in Section 3, these topics and their relevance to future military decision-making are developed in greater detail.

1.3.1 Decision-Making

What is involved when an individual or group makes a decision? Decision-making as a term covers a lot of territory. In general terms, it can be said that decision-makers (1) define the problem, (2) identify and analyze possible courses of action, and (3) select a course of action. In Section 3, strategies that people use to make decisions are reviewed briefly. Other topics to be addressed are how group decision-making differs from individual decision-making and how distributed decision-making differs from collocated decision-making. It should be noted here that decision-making is a term that can cover a wide range of cognitive behaviors, and this most broad usage is probably appropriate for this *Review & Analysis*. That is, people working in teams in the future battlefield will be engaging in planning, generation of possible courses of action, and analyses of battle damage, all of which contribute to decision-making. So this *Review & Analysis* will discuss "decision-making" in the widest of all possible senses. Just as solution generation follows a definition of the problem, awareness of the problem precedes definition of the problem, so situation assessment and situation awareness will be addressed in this *Review & Analysis* as well.

1.3.2 Collaborative Decision-Making

Collaborative decision-making implies the existence of more than one decision-maker who work together whether a group or team. Orasanu and Salas (1993) state that a team consists of two or more individuals who rely on more than one source of information, share a set of common goals, and have defined roles and responsibilities. There is interdependence and coordination among members. Teams are also characterized by adaptive management of the team's resources. Team members possess task-relevant knowledge. Groups are distinguished from teams in that teams are more differentiated and interdependent, whereas groups are more homogeneous and the members more interchangeable. Since the future battlefield will contain a variety of decision environments, the distinction between groups and teams will not be emphasized in this *Review & Analysis*. These terms will be used interchangeably.

1.3.3 Distributed Decision-Making

Several aspects of a team can be distributed. Authority, responsibility, task knowledge, and expertise are usually inherently distributed in all teams. For instance, one person is usually in charge, so authority is unequal. Responsibilities are assigned, and task knowledge and expertise are differentiated. This leaves location as the defining characteristic of distributed teams. A distributed team, in the context of this *Review & Analysis* and most of the scientific literature (Orasanu and Salas, 1993), is a team with one or more members geographically separated from the others.

2.0 APPROACH

As military decision-makers prepare to work, the task they face has many components. Decision-makers will be required to work together as a team, and may be working in war rooms and ground stations far apart from one another. They will be facing extreme levels of stress from the critical nature of their mission, and the time factor will be extraordinary. Given these conditions, how can good decisions be made? Are some people better decision-makers than others? Can the Air Force use information about who makes a good decision-maker in its selection criteria? Can effective group decision-making strategies be taught? Are good decision-makers born or made? What are the steps that groups undertake as they reach consensus? What is the state of the science regarding group decision-making? This *Review & Analysis* sought to answer these questions by analyzing an overview of the literature on collaborative distributed decision-making and the future battlefield.

Information for this *Review & Analysis* was gathered from several sources. The bulk of information was derived from Air Force and published scientific literature, including books, technical reports, and journals from the fields of military forecasting, decision-making, team processes, and communication. Relevant literature was identified subsequent to a comprehensive computerized search of the literature. Literature searches were performed on several databases, including:

- Defense Technical Information Center (DTIC) Technical Reports (TR)
- DTIC CD-ROM
- DTIC Work Unit Information Summary (WUIS)
- National Aeronautics and Space Administration Remote Control (NASA Recon)
- PsycINFO©
- National Technical Information Service (NTIS)
- Dissertation Abstracts Online
- Books-in-Print
- Educational Resource Information Center (ERIC)
- Jane's Defense and Aerospace

Relevant and recent literature and researchers were identified and this information was used to access other sources. From over a thousand citations (see Volumes 2 and 3), journal articles, technical reports, and book chapters from the past decade, created in or translated into English, were obtained, reviewed, and analyzed for this report. In addition to databases of literature, additional information was obtained through World Wide Web newsgroups, internal Air Force instructions and other documents, subject matter experts, and electronic documents.

3.0 FINDINGS

3.1 THE STUDY OF DECISION-MAKING

This section will describe the steps involved in decision-making, discuss some of the major theoretical frameworks regarding decision-making, and present the advantages and disadvantages of collaborative and distributed decision-making. Then, literature about what makes an effective decision-making group is presented. This literature will be examined according to three thrusts—how the Air Force can control three kinds of variables. Environmental variables (for instance, the availability of technology) can be directly controlled by the Air Force. Factors inherent to the individual, traits, and aptitudes, can be the basis for Air Force selection procedures. Finally, behaviors that can be learned can be used to design decision-making training courses.

3.1.1 Steps in Decision-Making

Literature abounds which lists the different steps involved in the making of a decision, but generally, decision-making is considered to involve these processes:

- Problem Recognition
- Information Gathering
- Development of Options
- Implementation of Options

It is important to note a term at this point that is used in many contexts, and to define what it means here. The Problem Recognition stage can be said to incorporate the state of being aware of a situation. Situational (or Situation) Awareness (SA), "the capability to appropriately assess yourself, your system, and your environment to make the right decision at the right time," is a critical element of decision-making (Vidulich, 1992, cited in Kokorian, 1995). Endsley and Jones (1997) divide SA into these three high-level stages:

- ***Perception*** of elements in the environment,
- ***Comprehension*** of the current situation, and
- ***Projection*** of future status.

The resulting information from these steps serves as a major input to decision-making. In fact, SA is often considered *the* critical component of decision-making (Endsley and Jones, 1997; Noble, 1993). Thus, effective decision-making is linked to effective and accurate SA.

This discussion of the stages in decision-making give us some familiarity with the behaviors of individuals and groups involved in group decision-making, We now need to consider the differences between individual and group decision-making, and collocated and distributed decision-making.

3.1.2 Theoretical Perspective

A brief look at the history of decision-making shows a recent leap from a classical to a naturalistic perspective.

3.1.2.1 Classical Vs. Naturalistic Decision-Making

The classical theories were characterized by normative models of decision behavior, focusing on the correct way to make a decision. Normative models of decision-making focused on the process of option generation and simultaneous evaluation to choose a course of action (Wright, 1984). Researchers in the mid-1980s who were facing more applied issues such as those found in decision support, system design, and training, were thwarted by the classical approach, which was seen to be narrow, with contrived decision-making situations which were of little consequence to real world decision-makers (Cannon-Bowers et al., 1996). A small group of decision researchers met in Dayton, Ohio in 1989 to discuss a new alternative, naturalistic decision-making (NDM). Naturalistic decision-makers focus on the description of how people make decisions, rather than a prescriptive approach. NDM emphasizes complex, real-life decision-making environments. An edited volume followed this conference (Klein, Orasanu, Calderwood, & Zsambok, 1993). NDM has made important contributions to the study of decision-making. It has focused attention on the experience that decision-makers bring to bear in making good decisions. NDM-related models indicate that different cognitive strategies are used for static versus temporally evolving situations. Also, these models indicate that action and perception are crucial aspects of NDM. They state that human resources are limited, and that human decision-making competence, rather than dysfunction, should be emphasized (Cannon-Bowers et al., 1996).

3.1.2.2 Characteristics of Naturalistic Decision-Making (NDM)

NDM occurs in situations characterized by these eight factors (Orasanu & Connolly, 1993, p. 7), which can be seen in many current and future military scenarios:

1. Ill-structured problems
2. Uncertain dynamic environments
3. Shifting, ill-defined, or competing goals
4. Action/feedback loops
5. Time stress
6. High stakes
7. Multiple players
8. Organizational norms and goals

3.1.2.3 Recognition-Primed Decision-Making Theory

The dominant NDM theory is Recognition-Primed Decision-Making (RPD)(Klein, 1989). Klein and others base this theory on ten years of observation of military operations and other operational command situations. RPD asserts that those in command generate courses of action immediately after a rapid assessment of the situation. The commander may often recall a single course of action once employed in a similar situation. Recognizing the similarity of one situation to a former one is the key to RPD. The commander may then run through the chosen option by a mental simulation in order to assess its implications before putting it into action. Klein (1989) determined that 80 percent of fire fighter commanders' decisions were recognition-primed. To the decision-maker, use of RPD feels like an intuitive response rather than an analytical judgment of alternative options. The following list characterizes tenets of RPD (Klein, 1993):

- In operational settings, people try to find the first course of action that works, not the best one.
- Decision-making consists of two aspects—assessing the situation, and selecting a course of action.
- Experienced decision-makers can usually assess the situation quickly and accurately.

- Once the situation is understood, the course of action is usually obvious.
- Decision-makers often must be prepared to act without fully examining the parameters and contingencies.
- Decision-making and problem-solving are inter-related.
- Decision-makers arrive at a course of action by generating pertinent opinions rather than filtering out unacceptable ones.

RPD is an apt model for military decision-making in many ways. The eight characteristics listed above can be found in many military decision-making environments. Researchers in many operational/ incident commanders across diverse domains have found Klein's work to be applicable. In a study of officers in the London Fire Brigade, Hendry and Burke (1995) concluded that 81 percent of the officers' decisions were reached without appraisal of an alternative option. Serfaty, Macmillan, Entin, and Entin (in press) used a naturalistic approach in an examination of course-of-action decisions among US Army commanders. Pascual, Henderson, Fernall, Ahmed, and McGahan (1994) found that naturalistic strategies accounted for 87 percent of the decisions made by officers of a British Army command post simulator. The Tactical Decision-Making Under Stress (TADMUS) project, examining US Naval Commanders' warfare decision-making processes, with the objective of designing better training and support software, has also adopted an RPD framework (Cannon-Bowers, Salas, & Grossman, 1991).

3.1.3 Concepts of Collaborative and Distributed Decision-Making

These stages in decision-making give us some familiarity with the behaviors of individuals and groups involved in such a task. We now need to consider the differences between individual and group, and collocated and distributed, decision-making.

3.1.3.1 Collaborative --Group vs. Individual

This section reviews the differences between decision-making by an individual and decision-making in a group context. As we move from what is known about individuals and decision-making, Klein (1993) says:

> The idea is to take what we know about the way individuals think, and bump it up one level as a model of teams. A cognitive model of team decision-making views a team as an intelligent entity, subject to all the cognitive limitations of an individual—limited memory, limited attention, limited situation assessment capabilities, and so on. The intent of the cognitive framework is to focus attention on the team, rather than on the team members, and to take advantage of our knowledge of individuals to better understand team decision-making.
> (p. 126)

Another view of group versus individual decision-making comes from a study of aircrew decision-making (Korkorian, 1995). Compared to decision-making by individuals, cockpit crew decision-making is managed, that is, the captain has responsibility for making decisions but is supported by other crew members, and outside the cockpit by air traffic controllers and dispatchers. Team decision-making is better than individual decision-making because there is greater cognitive capacity to consider a larger picture, more alternatives, and the team is more likely to identify more possible errors. Team members may feel less stress when the stress comes from public scrutiny of performance, because failures of team members may be masked (Klein, 1993). On the downside, group decision-making suffers if poor communication among members leads to erroneous sharing of mental models. In addition, errors can breed through the crew, leading to false collective confidence. Klein (1993) indicates that ambiguity can cascade through teams, since no member can be sure of understanding how others are interpreting events. Klein (1993) states that stressors may have a greater effect on teams than individuals, since the stress would disrupt team interactions as well as the performance of individuals. While individuals making decisions often do well under stress, with many studies showing little effect of noise and time, groups may be susceptible to time pressure. Time pressure may lead the group to throw off coordination among members. In addition, Klein also states that individuals can use recognition decision strategies to save time, but groups do not have such shortcuts available to them. Clearly, there is a terrific benefit in general to group versus individual decision-making, since the collective mental abilities and task knowledge of a group are far superior to that of any individual. Auditory noise can degrade team communication, and high workload imposes a differentially greater burden on teams than individuals because coordination efforts must be increased.

3.1.3.1.1 Group Planning—An Example

In reality, what does a group activity look like? Who might participate? Who coordinates with whom? What kinds of information might be transmitted? To put these factors into an applied military context, we can examine the steps involved in a group planning activity, from Klein and Miller's (1996) observation of a Joint Forces Air Component Command exercise. They show these functions, sources, and communications as being the steps taken during the production of air combat orders.

Problem Detection

- Joint Intelligence Cell provides intelligence to many groups, including the Joint Force Air Component Commander (JFACC) staff
- JFACC intelligence cells feeds intelligence to JFACC staff
- Problems are identified and corrected during briefings in the intelligence cell and at the Joint Target Coordination Board
- Combat Plans and Combat Operations detect problems as plan is worked out, and implemented, respectively
- Smaller teams within the JFACC staff detect low-level problems such as flight deconfliction

Information Gathering

- Information gathered by intelligence from sensors and other data collecting assets such as imagery, gun camera video, electronic interception, forward observers, etc.
- Members of Combat Plans include experts on platforms and weapons systems who can answer questions

Formulating the Course of Action

- Target prioritizing is done by the Intelligence Cell from component target nominations
- Course of action is captured in the Joint Integrated Prioritized Target List (JIPTL), Master Air Attack Plan (MAAP), and finally in the Air Tasking Orders (ATO)
- Joint Targeting Cell Board (JTCB) approves and/or modifies the course of action
- Detailing the Course of Action
- Staff in Combat Plans, with input from the wings, detail the course of action in isolation from the staff that formulated the course of action

Evaluating the Plan

- Corrections made as the plan is being developed
- Evaluation accomplished in meetings, especially by the JTCB
- No formal evaluation mechanism

Problem Representation

- Tactical maps and overlays at each level of planning
- Numerous representations that differ at different levels of planning, including Concept of Operations (CONOPS), target nominations, briefings, JIPTL, MAAP, ATO, etc.
- Generation and transmission of Commander's intent and guidance documents (p.24)

3.1.3.2 Distributed vs. Collocated

We've discussed some of the factors affecting group decision-making as opposed to individual decision-making. Now we need to address the distributive nature of decision-making. How does the distributive component affect decision-making? What are the differences between collocated groups and geographically dispersed groups? Obviously, dispersed groups rely on communications technology, which certainly affects human communication. Support for collaborative work includes tools such as electronic mail, bulletin boards, shared information systems, video-conferencing, and electronic meeting rooms. These technologies allow individuals who are dispersed in time and location to work on common tasks. This area has been supported by systems known as groupware, group decision support systems, computer-supported cooperative work, and computer-supported collaborative work (Hiltz, Dufner, Fjermestad, Kim, Ocker, Rana, & Turoff, 1996). By the year 2025, it is likely that the information environment will incorporate elements of virtual reality. Networked, distributed VR would allow immersive, multi-participant interaction. University of Washington's Human Interface Technology Laboratory demonstrated a common virtual world called GreenSpace for users in Tokyo and Seattle, via a narrow-band communication link. Users had a representation of being in the same room with one another. Compared to teleconferencing, VR offers an immersive, 3-D experience.

A benefit of a distributed decision-making team is that members may be positioned in ways that extend the reach of a collocated team (Orasanu & Salas, 1993). Different information is available through the visual scene, for example, when members of a group are not located together. More computer and other hardware resources may be available when a group is not collocated. The downside of geographic dispersion is that communication information is lost when communication is not face-to-face. That is, facial expressions, volume, and emphasis that we observe when we are in the same physical space as another person, may not be available through an electronic medium. Advances in virtual reality may alleviate some of this information loss. The geographical separation also places another burden on the team, that of differentiating tasks and distributing them. In other words, the management load increases when the team is dispersed.

3.2 EFFECTIVE DECISION-MAKING GROUPS – ENVIRONMENT AND COMPOSITION, INDIVIDUAL DIFFERENCES, AND SKILLS

The Air Force needs to know how to prepare for the next century. We acknowledge that the future battlefield will contain as a crucial element, distributed collaborative decision-making. How the Air Force can select or train good decision-makers is the focus of this section, which details some of the research regarding the influences on group function. What can we extract from the scientific literature about effective teams? Studies are full of indicators regarding innate human characteristics, cognitive abilities, factors external to the group, group processes, and ways of behaving. What sense can we bring to these data? What characteristics of effective decision-making teams can we use in Air Force selection and training policies? This section highlights some of the ongoing research programs into training methods for effective decision-making. Literature was chosen that focused on either personality traits of effective decision-makers or on strategies or ways of behaving in a group, that could be trained.

This *Review & Analysis* has discussed some of the issues involved in the study of collaborative distributed decision-making. At this point, we need to extract some information that is useful to the Air Force in its strategic planning for the next decades. The tack will switch now to effective decision-making, and how an effective decision-making unit can be generated. This section will focus on three main topics: (1) the group's make-up and environment, (2) individual abilities and traits, and (3) decision-making strategies that characterize good decision-makers. As was mentioned earlier, some of these variables are totally under the control of the Air Force; others are inherent to the individual and would be important to Air Force selection processes; while other factors are trainable.

3.2.1 Effective Decision-Making Groups—The Environment and Group Composition

This section describes some factors that the Air Force can impose upon group processes. These variables are external to the individual, that is, the Air Force can determine for example, the composition of the group, and the resources available to the group. The work of Levine and Moreland (cited in Kokorian, 1995) provides a good beginning to this discussion. Their work summarizes the factors that influence decision-making groups, including the environment, individual traits, and strategies. Since their work emphasizes, but extends beyond, environmental issues, it will serve as a good introduction to the topic of factors that engender good decision-making. Levine and Moreland provide this list of elements that affect group behavior. They use the word "ecology" as it refers to the physical, social, and temporal environment in which the group works. The *context* of group behavior needs to be taken into account. Context items include the following:

> **Physical Environment** -- the impact of computerization on changes to group communication, norms and status systems, and factors influencing a sense of group territoriality and shared ownership over physical and temporal space. (p. 4)
>
> **Social Environment** -- a move towards models based on intra-group collaboration through such processes as negotiation, acquisition of information, impression management and buffering (defense), research on the influence of culture on groups and groups on culture. (p. 4)
>
> **Temporal Environment** -- which refers both to the development level of the group (new or mature) and to the influence of time limits and deadlines on group behavior. (p. 4, 5).

Levine and Moreland also state that group composition is an important determinant of group behavior. Important variables that influence group interactions include group size, and demographic, affective, and skills characteristics of a group. Salience between characteristics of group members is also important, as is mode of conflict resolution. Also to be considered is the pattern of relationships among group members.

Many of these environmental variables could be controlled externally, that is, by Air Force assignments of individuals to groups, or the provision of technology, and the nature of the constraints and freedoms extended to the group.

3.2.2 Effective Decision-Making Groups: Individual Differences

Selection of personnel by Air Force planners is the issue with variables of this type. It is important for Air Force planners and strategists to consider ways in which personnel selection can be modified in future decades so that Air Force personnel will be effective decision-makers as well as competent in their technical area. This section reviews some of the skills, abilities, and characteristics of people who will contribute to effective team decision-making. The drawback to this area of research is that much of it is situation-specific. There appears to be no consensus about what innate variables predict good decision-making.

Individual differences, including abilities and personality traits, have been considered by many researchers as a means to predict team or group performance. There is general consensus among researchers that individual difference variables, including personality, can have a significant influence on group functioning (Hogan, Raza, Sampson, Miller, & Salas, 1989; Kichuk, 1996; Hare, 1962). While this notion is generally supported, the exact nature of the impact of personality on groups is not easy to quantify.

Larson and LaFasto (cited in Kokorian, 1995) cite certain factors as important to membership of an effective decision-making team. While some of the factors they cite are skill-based (the subject of the next section), others are considered inherent to the individual. For instance, Larson and LaFasto indicate personal competencies such as intellectual ability, results orientation, team orientation, maturity, and personal presence are important, as are a strong desire to contribute and the ability collaborate effectively.

Hogan et al. (1989) conducted a two and one-half year project for the Navy investigating the impact of personality on team performance. They concluded that "the personality characteristics associated with optimal team performance depend on the type of task" (p. 3). Specifically, their research supported the following personality and task combinations for optimal performance: teams composed of

- *reserved, conscientiousness rule-followers* perform best on *realistic* tasks.
- *extroverted, independent risk takers* perform best on *investigative* tasks.
- *daring individuals* with broad interests perform best on *artistic* tasks.
- *conscientious, planful, affiliative* people perform best on *social* tasks.
- *intellectually focused*, emotionally well-adjusted, *independent* people who are not personally ambitious perform best on *enterprising* tasks.
- *reserved, conscientious rule followers* who are *intellectually motivated* perform best on *conventional tasks*. (p. 6)

In other studies, the Myers-Briggs Type Indicator (MBTI) was used to measure the correlate between personality and group performance. One such project examined the decision-making ability of groups formed with dissimilar personality types and those not formed by dissimilar types. The research concluded that the teams formed by dissimilar MBTI personality types did score higher than teams formed without the MBTI, but they were statistically no more effective (Page, 1991). Another study examined the relationship between team members' MBTI scores and the teams' subsequent performance. The results indicate that "low heterogeneity among the team members' scores on the factor of *extraversion* was found to correlate positively and significantly to the team's actual performance" (Kichuk, 1996, p. 1). Further, it was noted that "heterogeneity among the team members' scores on the factor *emotional stability* was found to be positively related to the actual performance of the team" (Kichuk, 1996, p. 1). In addition, she states that while one slightly neurotic person (low on the *emotional stability* factor) may be beneficial to team performance, more than one in a small group is detrimental to team performance.

Hare (1962) discusses the effects of personality combinations in small group interactions. In general, he states that "a high group mean on a personality trait usually results in a similar type of behavior for the group" (p. 195). Also, "high variance on other traits may produce more effective groups if the task calls for variability in individual performance, or conflict if the task calls for similarity of individual performance" (p.195). In addition, he makes the following group distinctions:

- High group means … [for] *adventuresomeness, vigor, dominance, purposefulness, orderliness, willed application, and freedom from anxiety* are associated with … high performance on tasks requiring *vigorous coordinated action.*

- High group means … [for] *paranoid suspiciousness, nervous tension, emotional immaturity, worrying suspicious anxiety, and lack of self-sufficiency* are associated with low observer ratings on *degree of leadership, orderliness, we-feeling, level of motivation, degree of group organization and interdependence, and with high ratings on frustration.*

- High variances among members on personality traits of *surgency …, radicalism …, and high variance on degree of internalization of social norms, along with high mean friendliness, intelligence, and general level of radicalism,* are associated with a high level of *accuracy on tasks requiring a judgment of facts from inferential grounds.*

- High variances on personality measures of *tough- versus tender-mindedness, "Bohemian aggressiveness," and paranoid suspiciousness* are associated *with dislike for a task of resolving opinion and attitude differences, slowness in ranking attitude preferences, and a feeling by members* that other members hinder group progress.

- Low *variance or uniformity* [of emotional maturity] is found to be associated with a certain *optimism and confidence in level of aspiration.*

- Measured personality traits of members *involving emotional maturity, friendly co-operativeness, trustfulness, and adaptability, adventuresomeness, willed application, and freedom from anxiety* were positively related to *smooth and effective group functioning.*

- The characteristics of *paranoid suspiciousness, eccentricity, and coolness* to others were found to be *negatively related to smooth functioning. (*p. 191-3)

Studies have also been conducted in Air Force situations to examine the utility of personality measures and their corresponding evaluative tests for aircrew selection. Pedersen, Allan, Laue, Johnson, and Siem (1992) conclude that the Myers-Briggs Type Indicator is the most viable option to guide future AF research in the selection of personnel based on personality. The Five-Factor Model "provides a structural description of the basic dimensions of personality" (*extraversion; agreeableness; conscientiousness; emotional stability; intellect)*, and thus "serves as a scientific framework for the development of predictor constructs for selection" (p. 16). However, Dolgin and Gibb's (1989) review of personality literature in relation to aircrew selection revealed that most personality tests do not produce valid measures for pilot selection. They do however recommend continued research of the Defense Mechanism test, Personality Research form, and the Strong Vocational Interest Blank as they appear to be both effective pilot selection tools and soundly designed measures. Nonetheless, "there is still doubt as to the predictive ability of any personality measure for predicting aircrew performance (Pedersen et al., 1992, p. 23).

The information about aptitudes and personality traits, and how to combine these variables into an optimum mix of individuals, represents some interesting findings. Yet much of this research results in findings that are situation-specific. A strong answer about the inherent characteristics of a good group decision-maker does not yet exist.

3.2.3 Effective Decision-Making Groups – Skills and Strategies through Experience

This section has reported on some of the variables that affect group processes. Importantly, this review of the literature revealed that while some studies focus on personality characteristics of good decision-makers, or the effects of group composition or environment, a great many studies focus, instead, on what can be done to any set of individuals to turn them into good group decision-makers. There is a plethora of evidence that learning is the crucial element for good group decision-making—that expert decision-makers are experts because they are experienced decision-makers. What follow are three studies that describe the capabilities and strategies of experienced group decision-makers. There is consensus about what makes good decision-makers or a good decision-making teams—*experience*. Experienced decision-makers are expert decision-makers. This finding has major implications for Air Force personnel and training programs. This is one of the most important sections of this *Review & Analysis*. The findings here represent some of the best research performed in the area of group decision-making, and the results of all the research are more consistent in this area of strategies than in the areas of individual differences or environment.

Orasanu (cited in Kokorian, 1995) presents these characteristic ways in which effective teams behave. Expert decision-making teams are characterized by the following:

- ***Situational Awareness***—that crews are alert to developing situations, sensitive to clues, and aware of their implications

- ***Planfulness***—that crews work out plans and strategies for reaching their goals in advance, that they prepare for contingencies, determine what information they need, and monitor their progress

- ***Shared Mental Models***—that crews communicate efficiently enough to create a shared big picture through which they use resources, make sure they are all solving the same problem, and solve it in a coordinated way

- ***Resource Management***—that groups use resources efficiently and explicitly by setting priorities, scheduling tasks, allocating responsibilities, and including thinking time (p. 33)

Kanki, Lozito, and Foushee (1989) state that experienced teams can become so efficient in their work that they are able to overcome effects of fatigue. They describe an experienced team as

- sharing a mental model
- using conventionalized conversation pattern
- using task-relevant talk

Gordon (1992) describes an experienced decision-maker as

- having better organized knowledge structures
- perceiving and organizing on an abstract level
- perceiving problems in meaningful patterns
- using procedural knowledge and forward inferencing techniques

Shanteau (1988) states that an experienced decision-maker

- can discern relevant from irrelevant information
- can simplify complexities
- knows when to make exceptions
- can choose appropriate problems to solve
- has content area knowledge
- has cognitive automaticity

While the earlier sections reported findings about skills, abilities, personality, and group composition, those findings were disparate from one another and hard to generalize to many kinds of decision-making environments. However, the work in this current section shows much more consensus and generalizability. These studies all concur on the benefits of training, of being an experienced decision-maker. As Air Force strategists plan for the next century, the implications for training cannot be overemphasized.

3.3 COLLABORATIVE DISTRIBUTED DECISION-MAKING RESEARCH PROGRAM—REPRESENTATIVE EFFORTS FROM AIR FORCE, ARMY, NAVY, AND OTHER ARENAS

This section reviews programs and research on collaborative distributed decision-making, largely from the military arena. The first area examined, Current DoD Distributed Collaborative Decision-Making Programs, focuses on uses of this process already in effect throughout the Department of Defense. Subsequent areas focus on research programs.

3.3.1 Current DoD Distributed Collaborative Decision-Making Programs

Many of the DoD futuristic and planning documents include functions and processes that presume collaborative decision-making. Recognizing how crucial the collaborative nature of future decision-making is, several military programs are emphasizing this emerging research area. Army, Navy, and Air Force are all supporting collaborative distributed decision-making research, results of which will be discussed later. The following are just a few of the decision-making efforts in a variety of arenas, to show the diversity of interest in collaborative decision-making.

In May of 1996, a DOD Collaborative Technology Users Network forum was held with representatives from the HQ USMC staff, HQ USAF Innovation Center, the Defense Information Systems Agency, National Defense University, US Army Community Family Support Center, US Navy Office of Civilian Personnel Management, and the US Navy Manpower and Personnel office. The purpose of this forum was to share information on creating joint models on how to make better use of collaborative meeting technology throughout the DOD. DARPA's Joint Task Force Advanced Technology program developed an "anchor desk" as a prototype to support a forward-deployed Joint Force commander with technologies such as computer-supported cooperative work technology and hypermedia technology. Notably, the Information Resources Management College offers a course to OS/GM 12-15 and military grades 0-4 and 0-6 on Group Decision-Making and Groupware. Also, a recent colloquium sponsored by the Human Factors and Ergonomics Society was titled *Multi-Crew Performance in Complex Military Systems*. The intent of this colloquium was to establish research approaches to complex military systems with a crew-centered perspective, using the various disciplines of human-computer interaction, computer-supported cooperative work, NDM, multi-crew aiding, cognitive engineering, situated cognition, and cooperative learning. Much of what was presented was prospective, or work in progress, but later we can describe a few emerging possibilities as an introduction to what we know about group decision-making and performance.

Research funded by the Air Force, Army, and Navy focuses on a wide range of issues. Some research is applied (the work of Klein for instance, which has resulted in a training program), whereas other programs are still theoretical, seeking to establish constructs and definitions, and to produce valid and reliable tools to measure whether a group is working effectively or not. Much of the work is directly relevant to the design of programs that train groups in effective decision-making. Although much is known about decision-making, at this stage, little is known about how to *train* decision-making for complex environments (Salas & Cannon-Bowers, 1996). Many current researchers in the field echo this conclusion. Kirlik, Walker, Fisk, and Nagel (1996, p. 289) state, about decision-making in complex environments, "... little is known about how best to train... this component of skilled behavior." Many of the issues brought up at the Human Factors and Ergonomics Society colloquium on *Multi-Crew Performance in Complex Military Systems* focused on defining relevant concepts and determining ways of measuring effective group performance, concerns which seem quite preliminary. While these endeavors seem to be in their early stages of development, there is much to be encouraged about. Many training programs are under development, and a great deal of research is being done on how to design an effective training program.

3.3.2 Current DoD Distributed Collaborative Decision-Making Research

While some work is being done in the military arena that focuses on traits and abilities (see Hogan, et al., 1989, for example), the bulk of the decision-making research focuses on skills training. The goals of these research programs are varied. The work of Klein and associates is applied in thrust, while the work of McNeese is very laboratory-based. This brief view of the many active programs shows the wide range of goals and focuses.

3.3.2.1 Modeling Army C^2 at the Brigade Level

Ensing and Knapp (1995) describe a methodology for modeling tasks and workload for optimal allocation of personnel resources in a Command and Control (C^2) Center. The approach is process-oriented, with the goal of decomposing cognition, decision, and group tasks. They make the point that while functional analyses and training manuals exist for many C^2centers, process analyses are marginal.

> A functional analysis or training document lists tasks such as "analyze" and "decide," without elaborating how these are performed. The Functional Description Documents are usually at too high a level and fail to account for the natural sequence of functions. Training manuals contained sequences but are confined to manual operations. Neither contains process steps for how to "analyze" or "decide" (p. 2).

This study decomposed these types of tasks into meaningful steps. Subject matter experts knew their end product—analysis or decision—but could not articulate how they got there. Facilitation of their mental steps took place, with such suggestions as "look at the ammo level on the board," "compare it with the ammo level on the plan." From the information thus extracted, the cognitive skills and abilities involved in analysis and deciding were derived.

A baseline work flow based on a Maneuver Brigade Tactical Operations Center was the basis for this model. A tiered approach was used to form an analysis framework. In the first tier, the work flow and mental processing demands were established. Each subsequent tier examined variations for workload comparisons. The second tier posed the question, "What effect would software have on staff processes, the cognitive skills required, the type of decisions imposed by the software, number of people required, and how they interact?" From these data, the third tier adds the effect of environmental stress factors, such as heat, noise, and vibration. For instance, the effect of noise on group interaction might be examined. Tier four examines the effects of removing face-to-face interaction on group processes. The fifth tier examines imperfect communications such as the effect of data exchange rates and limited voice communication. Using this tiered approach allows the researchers to isolate the effects of specific variables. Data are being gathered at this time to assess the effects of the different variables on C^2 group performance.

3.3.2.2 Advanced Team Decision-Making

Much of the work on designing training programs for effective group decision-making has been accomplished by Zsambok, Klein, Kyne, and Klinger (1993). These researchers based their training program principles on their observations of expert and inexpert decision-making groups. Groups from these organizations were studied or trained:

- Blue Flag at Hurlburt Field, FL
- AEGIS Combat Information Center at the Combat System Engineering Development Site (CSEDS), Moorestown, NJ
- Corps-level exercises at the US Army War College (AWC)
- Corps and division exercises at the US Army Command and General Staff College (USACGSC)
- Echelons above corps at the National Defense University (NDU)
- Brigade and battalion exercises at Fort Hood, TX; Fort Stewart, GA; and the National Training Center, Fort Irwin, CA
- Logistics teams at the Air Force Institute of Technology, Wright-Patterson Air Force Base, OH
- Helicopter teams at Fort Campbell, KY
- Commercial aviation crews at the NASA Ames Research Center, Moffett Field, CA

Zsambok et al. (1993) found these commonalties among effective teams, and produced a training programs upon these observations. The model of advanced team decision-making based on these observations includes these three basic concepts:

Team Identity is the extent to which a team sees itself as a unit that is interdependent, and uses that perspective during team decision-making. It is concerned with

- members' understanding of one another's roles and functions, how well they perform them, and the ability of the team to uncover hidden expertise
- the level of involvement of each member in the task and the ability of the team to engage all members
- the ability of the team members to temporarily leave their role or function and compensate for gaps in team performance
- the ability of the team to avoid micromanagement

Team Conceptual Level represents the team as an intelligent entity. It includes the group's ability to think, solve problems, and make decisions collectively. It also refers to the information explicitly known by all team members. It includes the abilities of teams to:

- envision goals and process plans to reach those goals, initially and iteratively
- focus appropriately on their time line, and the range of factors
- seek out gaps and ambiguities in their information base or situation assessment
- seek out divergent situation assessments before deciding on a single one

Team Self-Monitoring is really metacognition, and includes monitoring and regulating team performance, on such variables as ability to allocate, monitor, and re-prioritize.

Zsambok et al. (1993) believe that teams can learn to work effectively, that it is possible to train teams to behave in the ways just outlined. Being a good decision-maker is a skill that can be taught.

Klein (1993) and Cannon-Bowers, Tannenbaum, Salas, & Volpe (1995) have shown that teamwork skills are separate from work skills and they require, and benefit from, dedicated training. What is it that teams can learn to do? After training, teams can:

- adjust their responses in accordance with task demands (stress)
- employ implicit coordination strategies without overt communication by drawing upon common knowledge bases
- build complex associations between situational cues and appropriate responses and strategies

Klein, Zsambok, and Thordsen (1993) believe strongly in training designed specifically for team work, and that teampower is the resulting strength. The basic tenets of their training program focus on the following standards:

- Task exercises do not necessarily provide team training
- Instructors must learn how to train teamwork skills
- Team decision training can be added existing training
- Team decision skills can be reliably measured
- Participants can be taught to monitor their team in action and to make adjustments
- Teampower is important and it can be developed. (p. 42)

Others agree that training is essential to having an effective decision-making group. In a technical report on expert pilot decision-making, Adams and Lofaro (1992) state that the primary differences between being a beginner and being an expert can be the acquisition of knowledge and problem-solving skills. Expert performance can be defined as coming up with an appropriate response to problems or situations. The novice often solves problems by weak, domain-general methods, often working backwards from the goal. With experience or training, domain-specific production rules can be quickly developed. We know now that experienced decision-makers are expert decision-makers, so the question becomes, how can we turn naïve decision-makers into experienced decision-makers? Clearly, good decision-makers are made and not born.

In answer to the implied question, why train for teamwork, Klein et al. (1993) reply:

Many teams are not together very long, and do not have much time to come up to speed. That means the members have to be effective team decision-makers before they join the team.

The only way for that to happen is for them to learn the necessary team skills beforehand—through team training and prior experiences. (p. 42)

3.3.2.3 Air Force—Living Lab

One of the Air Force's collaborative distributed processes projects seems to have taken a step back, to a more theoretical examination of the factors involved in group work. The work of McNeese and others focuses on a more academic approach that seeks to investigate and define the mechanics of how people in groups work together. This way of dealing with decision-making training may prove to be a good choice, since its integrated approach of research and operations concerns may generate some solid training principles. Future work in the Living Lab will focus on natural modes of interaction among remote and collocated sites. McNeese (1996a) states:

> Cognitive science concerns for USAF new millennium initiatives revolve around potentially devastating requirements for attention, memory, group problem-solving, perception, learning, knowledge acquisition access, and motor control. These concerns may be jointly referred to as distributed cognition. A more theoretical approach is seen in the operations of the Living Lab, implemented at the Paul M. Fitts Human Engineering Laboratory of the Air Force's Armstrong Laboratory. While attempting to integrate theory and practice, the lab seeks to include the scientific research base community and the operational context/ warfighter community. (p. 264)

McNeese (1996b), in a description of the Living Lab, states that much of today's work, in many arenas, including the military, government, or private industry, is done in teams. Teams may contain smaller units referred to as multi-operator enclaves. Individuals who form one team may be members of other teams or enclaves that consume time and resources, and forge relationships in layers of complexity and change. The Living Lab is based on the belief that the social-organizational, psychological-cognitive, and technological components of collaboration should be included in the study of group-distributed decision-making. It is imperative that a broad systems approach be taken when a complex system of computer-supported collaborative work is being examined. One concept defined by Young and McNeese (cited in McNeese, 1996b) is situated cognition, as real-world problem-solving "wherein group members spontaneously generate knowledge in the context of a situation; coordinate multiple cognitive processes, applied though multiple paths; and pick up critical perceptual cues for potential solutions" (p.768). The framework that serves to organize the work of the Living Lab focuses on the interactions that are operative in any collaborative situation. Three paradigms are used to study collaborative processes:

3.3.2.3.1 Situated and Observed Cognition Studies (SOCS) program that seeks to understand collaborative practices within real-world work environments. Both practices and tools are highlighted.

3.3.2.3.2 Tradeoffs, Research, and Analysis in Collaborative Ergonomics (TRACE) project that examines tradeoffs as they occur in collaborating design teams.

3.3.2.3.3 JASPER (The Adventures of Jasper Woodbury: Rescue at Boone's Meadow) is a cooperative analogical problem-solving paradigm that investigates the roles of metacognition and perceptual expertise in collaborative settings. An example is a search and rescue planning task involving an ultralight airplane. One outcome of such an investigation is to determine the conditions within group collaboration that lead to a group member's use of knowledge as an individual.

3.3.2.4 Air Force—C3 STARS

A more applied Armstrong Laboratory program is called C3 STARS—C Simulation, Training and Research systems. Elliott, Neville, and Dalrymple (1996) focus on factors relating to Airborne Warning and Control System (AWACS) Weapons Director team performance as Weapons Directors participate in an air campaign scenario that includes time pressure, high complexity, and ambiguity. Imbedded ambiguous events allow the monitoring of team communications and decision-making. Communication, coordination, and situational awareness are assessed relative to performance and mission accomplishment, as predicted by the multi-level theory of decision-making in hierarchical teams with distributed expertise (Hollenbeck, Ilgen, Sego, Hedlund, Major, & Phillips, 1995).

The effectiveness of AWACS teams depends on effective communication, coordination, and accurate situational awareness. Team members must perform information transfer activities under the "fog and friction" of war, with time pressure and ambiguity, which may result in "ineffective communications, poor situational awareness, ineffective resource allocation, and friendly fire incidents" (Elliott et al., 1996, p. 4). There may be missing or incorrect information. How does a good team maintain communication and situational awareness under such circumstances? These are some of the issues C3 STARS attempts to answer.

To create a realistic distributed scenario, responsibilities of a typical air campaign are assigned to the High Value Asset Weapons Director, a Combat Air Patrol Weapons Director, and the STRIKE Weapons Director. The High Value Assets Weapons Director controls the C3 aircraft, including air refueling, electronic warfare operations, and reconnaissance. The Combat Air Patrol Weapons Director controls the Defensive Counter Air aircraft, and coordinates the fire of friendly surface-to-air missile assets, and team leadership. The planned bombing missions, unplanned Suppression of Enemy Air Defense missions, as
well as the unplanned Theater Missile Defense bombing missions are controlled by the STRIKE Weapons Director. Variables under investigation by this lab include

- team-level measures of operational outcomes
- team outcome measures
- preservation of assets
- destruction of enemy assets
- team efficiency/effectiveness measures
- kill ratio
- air refuelings completed
- completed switch actions
- friendly aircraft lost of fuel depletion
- fratricide
- penetration
- situational awareness measures
- total number of times assigned symbology (airborne/downed tracks) becomes uncorrelated

Data are currently being gathered and early results indicate that the measures used are reliable ones. Future analysis will concentrate on effects of information ambiguity, and what communication and coordination strategies are used by teams who deal effectively with ambiguity.

3.3.2.5 Navy—Tactical Decision-Making Under Stress (TADMUS)

Since 1990, the TADMUS program, which is sponsored by the Office of Naval Research, has sought to examine a variety of training issues involved in group decision-making in the context of a shipboard Combat Information Center (Cannon-Bowers, Salas, & Grossman, 1991). Johnston, Cannon-Bowers, and Smith-Jentsch (1995) describe performance in such a center as:

> ... inherently complex, and often characterized by a host of stressors. They include rapidly evolving, ambiguous scenarios, complex, multi-component decisions, information overload, auditory overload, command pressure, threat, adverse physical conditions, and rapid interaction requirements. Consequently, training to prepare operators for such situations must be designed not only to build crucial task and teamwork skills, but also to help teams be resilient to the impact of stress. (p. 1)

This large well-organized program has many thrusts, but the focus here will be a project on team training and performance.

Work of their own group and others (Klein, 1993) led the TADMUS group to believe that there is promise for effective training interventions for Combat Information Center teams. They hypothesize that:

- expert decision-makers rely on well-organized knowledge structures in making decision
- over time, expert decision-makers build complex associations between situational cue patterns and appropriate strategies/responses
- teamwork skills are separate and distinct from taskwork skills and hence require dedicated training
- expert teams have the ability to adjust their strategy in accordance with task demands (stress)
- expert team members employ implicit coordination strategies (i.e., without the need to communicate) by drawing on common or mutual knowledge bases. (Johnston et al., 1995, p. 2)

From this it follows that training needs to be developed that will allow team members to assess the environment and respond rapidly. Team members must be exposed to realistic scenarios so they can build their knowledge bases. For teams, this means that team members will require practice with others in the task environment so that team-specific competencies can develop (Cannon-Bowers, et al., 1995). Thus, the design of effective training systems will rely heavily on establishing performance criteria related to training objectives (Hall, Dwyer, Cannon-Bowers, Salas, & Volpe, 1993). Measures must be accurate and sensitive, and must generate corrective feedback as well (Cannon-Bowers & Salas, in press).

4.0 CONCLUSIONS AND RECOMMENDATIONS

4.1 SUMMARY OF FINDINGS

This *Review & Analysis* begins by discussing the basic steps in any decision-making action. First there is awareness of the situation to be addressed, followed by information-gathering, then generation of a plan and possibly some alternative plans, a choice among these alternatives, and then action. How these steps differ when groups rather than an individual are making the decision is discussed, with an emphasis on the benefits of group decision-making, such as increased cognitive resources, the ability to generate more solutions, and the opportunity for greater detection of errors. When decision-makers are distributed (geographically separated), they may have greater computer and other resources available to them as a group, and they may benefit from their different visual viewpoints. However, even with new immersive technology, the coordination and communication burden is increased when teams are dispersed.

Given our knowledge about how distributed collaborative decision-making takes place, what alternatives does the Air Force have in terms of selecting and training tomorrow's leaders? The state of the science regarding selection based on personality characteristics and aptitudes for decision-making is not optimistic. Although there has been a great deal of research on personality characteristics and group performance, the findings are for the most part too situation-specific to afford much utility to the Air Force. However, there is a plethora of literature that suggests one very important characteristic about the effective decision-maker, and that is, the effective decision-maker is an ***experienced*** decision-maker. This emphasis implies to the Air Force that training in decision-making is essential. Expertise can be obtained through real-life experience in decision-making, but occurs much more safely and efficiently through structured training exercises. A variety of researchers in a variety of contexts are investigating many of the important parameters in group decision-making training. The following paragraphs summarize the major military training research programs that focus on group decision-making.

4.1.1. Army Research

Important programs of interest to the Air Force include an Army program, Modeling Army C^2 at the Brigade Level, which focuses on the allocation of personnel resources in a C^2 Center. A baseline work flow based on a Maneuver Brigade Tactical Operations Center was the basis for this model. A tiered approach was used to form an analysis framework. In the first tier, the workflow and mental processing demands were established. Each subsequent tier examined variations for workload comparisons. The second tier posed the question, "What effect would software have on staff processes, the cognitive skills required, the type of decisions imposed by the software, number of people required, and how they interact?" From these data, the third tier adds the effect of environmental stress factors, such as heat, noise, and vibration. For instance, the effect of noise on group interaction might be examined. Tier four examines the effects of removing face-to-face interaction on group processes. The fifth tier examines imperfect communications such as the effect of data exchange rates and limited voice communication. Using this tiered approach allows the researchers to isolate the effects of specific variables. Data are being gathered at this time to assess the effects of the different variables on C^2 group performance.

4.1.2 Klein and Associates Research

Much of the work on designing training programs for effective group decision-making has been accomplished by Gary Klein, in conjunction with several associates. These researchers based their training program principles on their observations of expert and inexpert decision-making groups. The Klein group emphasizes the importance of these variables as characteristics of expert decision-making units:

Team Identity is the extent to which a team sees itself as a unit that is interdependent, and uses that perspective during team decision-making. *Team Conceptual Level* represents the team as an intelligent entity. It includes the group's ability to think, solve problems, and made decisions, collectively. It also refers to the information explicitly known by all team members. *Team Self-Monitoring* is really metacognition, and includes monitoring and regulating team performance, on such variables as ability to allocate, monitor, and re-prioritize.

4.1.3 Air Force Research

One of the Air Force's collaborative distributed processes projects seems to have taken a step back, to a more theoretical examination of the factors involved in group work. The work of McNeese and others focuses on a more academic approach which seeks to investigate and define the mechanics of how people in groups work together. This way of dealing with decision-making training may prove to be a good choice, since its integrated approach to research and operations concerns may generate some solid training principles. Future work in the Living Lab will focus on natural modes of interaction among remote and collated sites.

A more applied Armstrong Laboratory program is called C3 STARS—C Simulation, Training and Research systems. Elliott, Neville, and Dalrymple (1996) focus on factors relating to Airborne Warning and Control System (AWACS) Weapons Director team performance as Weapons Directors participate in an air campaign scenario which includes time pressure, high complexity, and ambiguity. Imbedded ambiguous events allow the monitoring of team communications and decision-making. Communication, coordination, and situational awareness are assessed relative to performance and mission accomplishment. This effort seeks to determine how a good team maintains communication and situational awareness under such circumstances.

4.1.4 Navy Research

Since 1990, the TADMUS program, which is sponsored by the Office of Naval Research, has sought to examine a variety of training issues involved in group decision-making in the context of a shipboard Combat Information Center. Performance in such a center is complex and stressful. Situations are characterized as rapidly evolving, ambiguous scenarios, complex, multi-component decisions, information overload, auditory overload, command pressure, threat, adverse physical conditions, and rapid interaction requirements. The focus of this Navy program is to devise training programs that not only build crucial task and teamwork skills, but also help teams be resilient to the impact of stressors.

This Review and Analysis sought to examine the science of decision-making, and to determine how the Air Force could exploit this discipline in the future battlespace and other military operations. The most important messages of this *Review & Analysis* for the Air Force are:

- Research on the differences between group and individual decision-making indicates that the biggest benefit of collaborative group decision-making is the group's increased cognitive resources, compared to that of a single individual.
- The greatest detriment to collaborative distributed decision-making is that we must rely on technology rather than face-to-face interactions, and subtleties of human communication may be lost.
- The best predictor of good decision-making is the experience of the decision-maker, the implication being that training for decision-making is paramount.
- While personality and other selection indices of the future may have better success, current tools do not offer a great deal of information about who will be a good decision-maker in general.
- All services are engaged in research into what variables are important in a group decision-making training program.

4.2 IMPLICATIONS FOR FUTURE AIR FORCE JOB SKILLS

The future Air Force will need to incorporate many aspects of group communications and collaboration into performance of its tasks. Excellent decision-making skills will have to be developed in training programs, including efforts to increase situation awareness. Although not the focus of this Review and Analysis, many other skills will be concomitant to group decision-making performance. For instance, Air Force personnel must be able to communicate across Services, nationalities, and cultures. To accomplish collaborative distributed work, Air Force personnel must also be able to use electronic media for information transmission. Future Air Force personnel will have to know how to operate and maintain complex computer communication systems, and how to find the essential information for a given situation. Stress management will be essential so that teams can function efficiently under the duress of emergency situations.

4.2.1 Recommended Group Decision-making Training Program

An ideal training program for the Air Force to implement would incorporate three aspects: communication, situation awareness, and decision-making.

4.2.1.1 Communication Skills Training

A specific set of skills that have a big impact on group processes can be taught as communication skills. Research presented in this *Review & Analysis* indicated that as groups gain experience, they learn efficient methods of communication. Teaching group communication skills should speed up the training of general group decision-making programs. The focus of communication skills training should be on:

- Narrow conversational focus
- Clear communication of definition, plans, strategies
- Stylized speech, predictable wording

Communication skills can be using such templates as clarity and narrow focus. Air traffic and pilot stylized speech can keep meanings clear and concise. Better communication allows teams to share mental models and to keep one another up-to-date on plans and plan revisions.

International groups pose a whole entirely new set of issues. Little research was found on specific problems that might need to be addressed as the future battlefield includes cooperative military-information efforts among nations, but there are some extant military programs that address cross-cultural issues in general. The emerging importance of the Far East, East Europe, and third world countries makes diversity and cross-cultural issues of prime importance. The Navy has Personal Response Programs and the Air Force has the USAF Special Operations School at Hurlbert Field, FL, which offers special-operations-related education, including cross-cultural communications. DTIC documents indicate DoD diversity training programs for Iran, Thailand, Central America, Greece, and Arab countries. In addition to this international focus, the corporate cultures of the different military services differ, so research needs to address better ways for military personnel to communicate across branches.

4.2.1.2 Situation Awareness Training

One area that needs further investigation and development is that of situational awareness training. Salas et al. (1995) say there is a dearth of training strategies for increasing group situation awareness, due in part to a lack of definitional clarity. As the science progresses, an ideal Air Force training program would include such a segment, addressing, as suggested by Klein et al. (1993), these topics:

- Recognizing cues
- Strengthening diagnostic and risk assessment skills
- Increasing metacognition
- Encouraging strategy development
- Understanding which conditions are a best match for particular strategies

4.2.1.3 Decision-Making Skills

As the research into the training of decision-making advances, the Air Force will be able to incorporate the best suggestions into its training program. The emphasis of Orasanu (cited in Kokorian, 1995) might serve as a starting point, urging that good decision-making teams, in addition to situation awareness, focus on planfulness, shared mental models, and resource management.

4.3 RECOMMENDED RESEARCH

Comparing the vision of the future Air Force with existing selection and training programs allows us to discern the presence of some areas that will need attention. The DoD programs and research efforts are making great progress in focusing attention on distributed collaborative decision-making, and in the creation of measures of group decision-making effectiveness. These research programs need to continue, so that training is administered to every person who might be involved in group decision-making in the context of his or her job.

Research into group decision-making responses has made such great strides over the last decade. To be more applicable to military training and selection, it is recommended that research continue, especially in the areas of:

- basic abilities and personality characteristics and how they influence decision-making
- tailored personality index development
- cost-effective selection or training of situational awareness skills
- documenting effective decision-making strategies under stress
- group composition and group process effects

4.4 CONCLUSIONS

The opening paragraph of this section summarized the implications for future Air Force personnel activities. Again, the major skills necessary from the point of view of this *Review & Analysis* are

- group decision-making skills, including situation awareness
- communication skills
- cross-cultural and diversity skills
- computer expertise

Manpower, Personnel, and Training (MPT) research needs to determine how best these skills can be generated. The two choices are of course, personnel selection and personnel training. The research points to the efficacy of training rather than selection of personnel, but both can be implemented by the Air Force. The first questions for MPT research are the following:

- If tools were available to better screen good decision-makers, would selection be more cost effective than training?
- What are the most efficient ways to train these skills?
- What is a reasonable interval for refresher training?
- How can these skills be best maintained?

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APPENDIX A, BRIEFING

Distributed Collaborative Communications & Decision-Making Briefing
Presented by Joyce Cameron
30 Jun 97

Developed by
Joyce A. Cameron and Frank C. Gentner

Based on the CSERIAC Review and Analysis, ***Technological Impact on Future Air Force Personnel & Training: Distributed Collaborative Decision-Making***, authored by

Barbara Palmer
Frank C. Gentner
Joyce A. Cameron
Jennifer I. Soest

Technological Impact on Future Air Force Personnel & Training:

Distributed Collaborative Communications & Decision-Making *

Joyce A. Cameron
Human Factors Analyst
June 30, 1997
Crew System Ergonomics Information Analysis Center
CSERIAC

* Based on CSERIAC *Review and Analysis:* ***Technological Impact on Future Air Force Personnel & Training: Distributed Collaborative Decision-Making*** by Barbara Palmer, Frank Gentner, Joyce Cameron, and Jennifer Soest.

Note: this forecast of the impacts of distributed communications and decision-making is derived from scientific literature, DoD, and Air Force planning documents. The statements herein contain an element of speculation and do not necessarily imply future official plans or policy.

Distributed Communications and Decision-Making: Overview

- Essential concepts and distinctions
- Importance to the emerging Air Force
- Research findings
- MPT research issues and directions

Essential Concepts and Distinctions

- Group vs. **Team**

  Team: "*people who must collaborate, to some degree, to achieve common goals*" (Dyer, 1987)

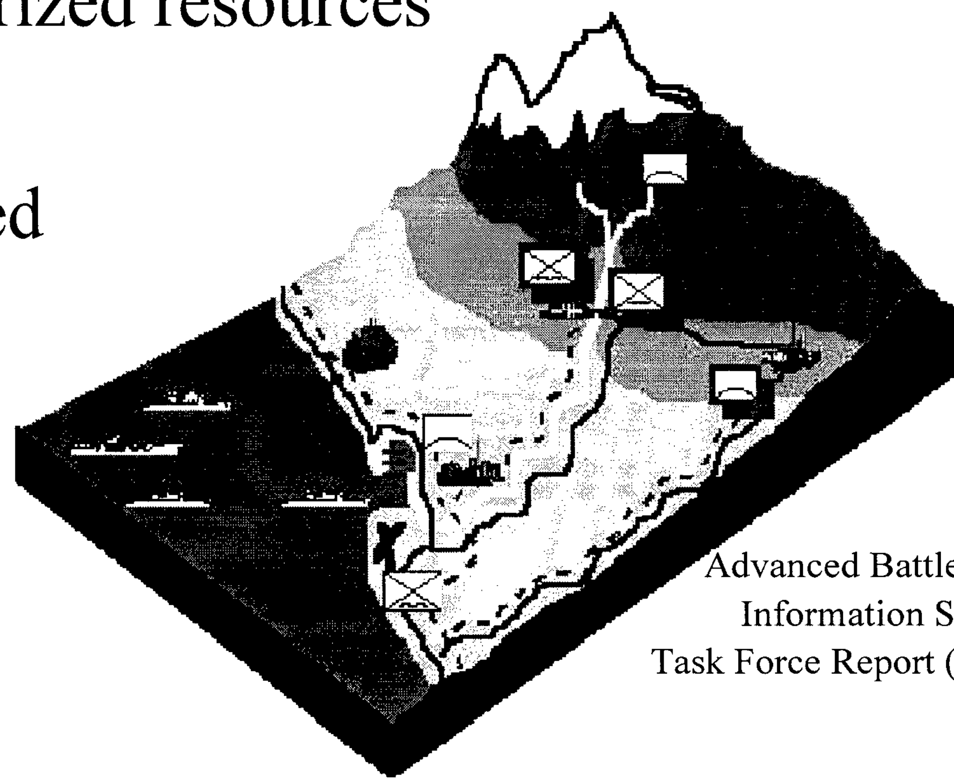
- Co-located vs. **Distributed Teams**
  - Team member location complicates interaction
- **Collaboration**
  - No one team member has all needed expertise
  - Requires interdependence and coordination

Essential Concepts and Distinctions (con't.)

- **Situation Awareness**
  - Used to describe human experience in complex, highly-automated environments
  - No universally accepted definition
  - Includes three components that inform decision-making
    1. Perception of elements in the environment
    2. Comprehension of the current situation
    3. Projection of future status

Essential Concepts and Distinctions (continued)

- **Battlespace Awareness**
  - Consistent understanding of situation across forces supported by computerized resources
  - Supports planning and decision-making related to force employment
  - Based on information fusion and resources available through the Information Grid



Advanced Battlespace Information System Task Force Report (1996)

Essential Concepts and Distinctions (con't.)

- **Information Grid or Infosphere**
  - Network of information resources and transmission systems that support
    - Future battlefield communications
    - Battlespace awareness
    - Distributed collaborative work
  - Is increasingly vulnerable

    "The more complex a system becomes, the more likely the chance of system failure"
    (Petersen, 1994)

Essential Concepts and Distinctions (con't.)

- **Decision-Making**
  - Problem definition/recognition
  - Gather information and develop options
  - Make and implement decision
- Two contrasting approaches
  - **Classic decision-making**
    - Prescriptive models
    - Based on research using contrived scenarios
  - **Naturalistic decision-making**
    - Descriptive models
    - Based on research in real-world situations

Essential Concepts and Distinctions (con't.)

- Characteristics of naturalistic decision-making situations
  - Ill-structured problems
  - Uncertain environment/incomplete information
  - Ill-defined goals
  - Multiple-event feedback loops
  - Time constraints
  - High stakes
  - Multiple players
  - Organizational goals differing from individuals' personal choices

Essential Concepts and Distinctions (con't.)

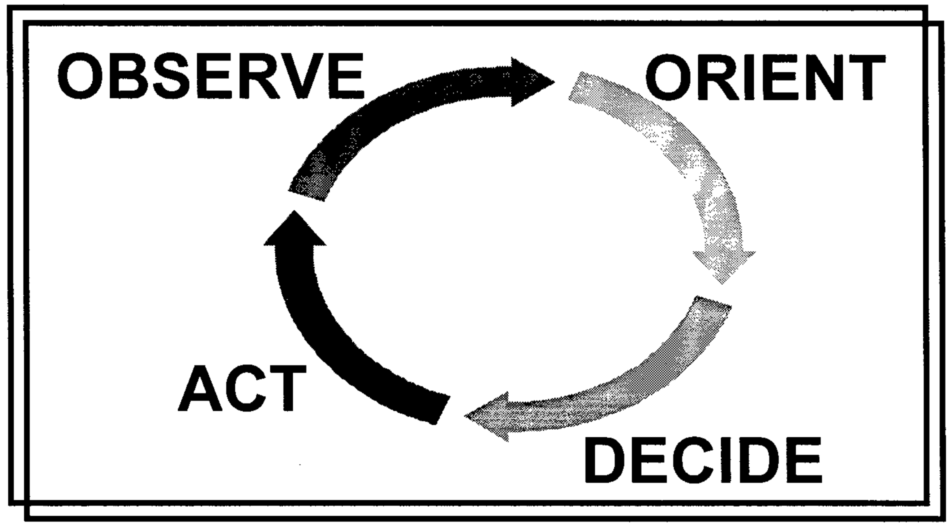
- **OODA Loop**
  - Model incorporating

    perceptual

    cognitive

    enactive

    components of decision-making

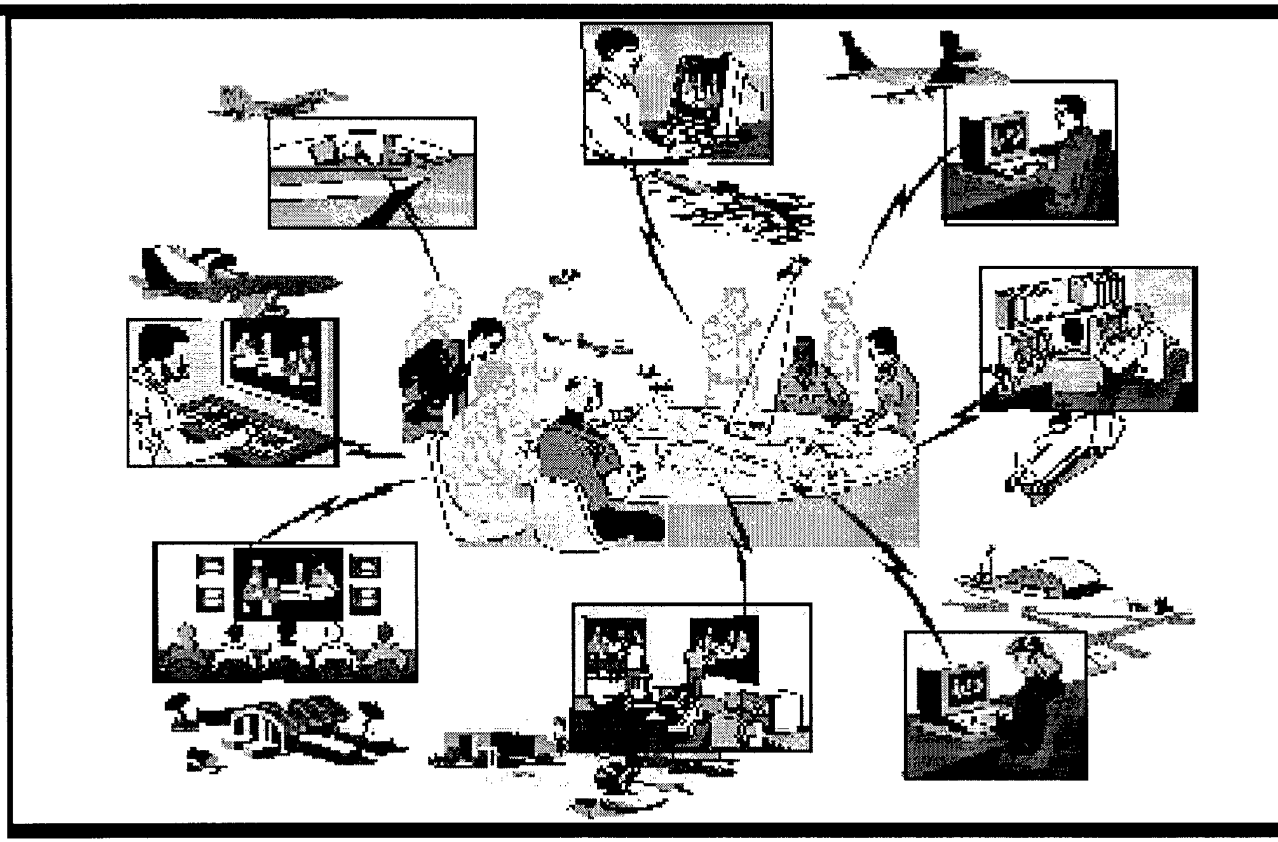


- **C^4I**
  - Command, Control, Communication, Computers and Intelligence

Distributed Communications and Decision-Making: Importance

- *Essential components* of Command and Control
  - Increasingly complex and difficult
    - Technological communication
    - Interpersonal interaction
    - Human/system interactions and work environment
  - Disrupted, altered, or missing communications can impair decision-making

Artist's Conception of Future C^4I System



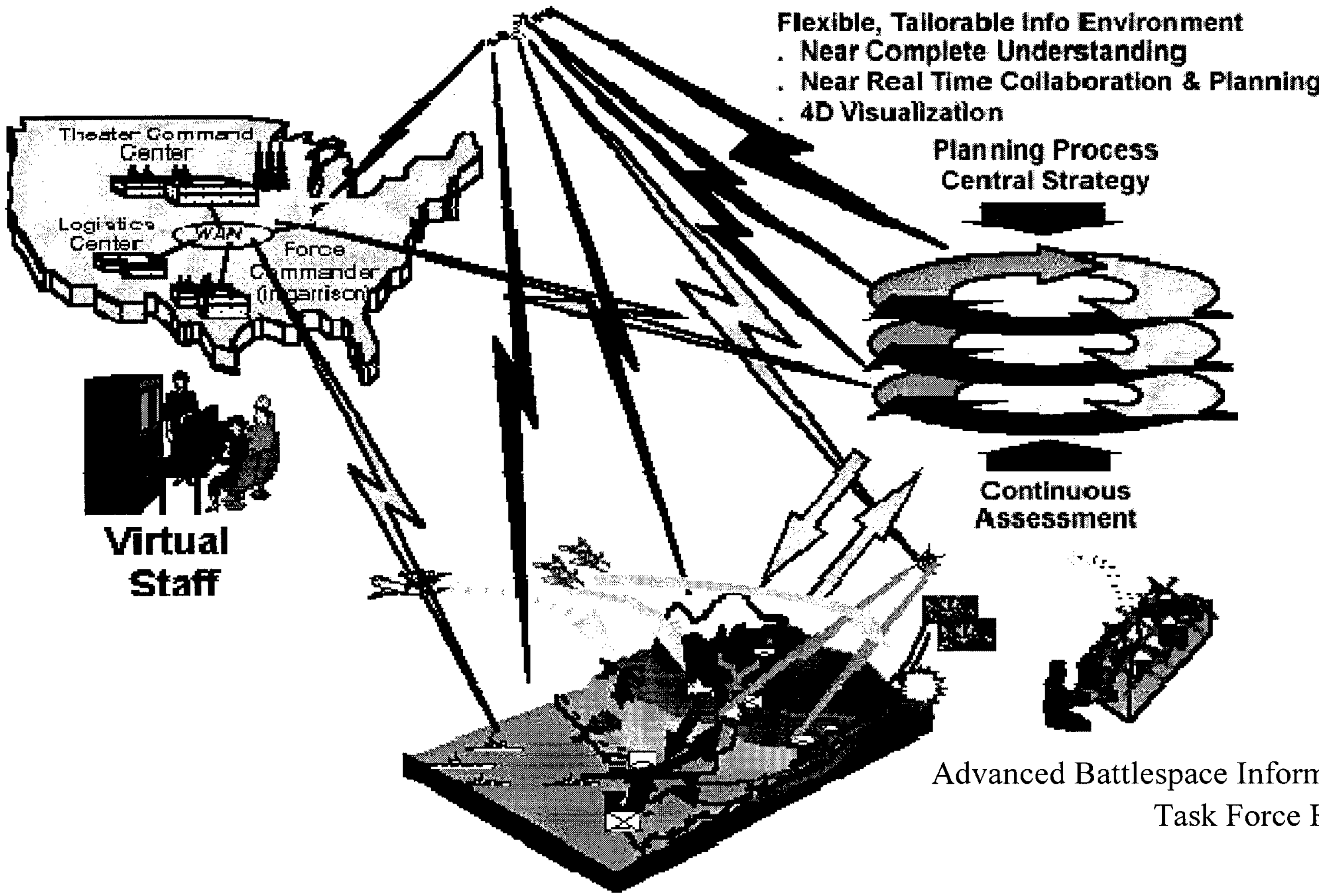
"...a distributed, collaborative and real-time interactive process that utilizes automated computer-aided decision processes."
(Sorenson & Haggarty, n.d.)

Graphic courtesy of Scientific Advisory Board (New World Vistas)

Changing Nature of Military Operations

- Joint Service Operations
- Operations Other Than War (OOTW)
- Expanded NATO and international operations
  - Requires increased multi-cultural communications

Future Battlespace



Advanced Battlespace Information System
Task Force Report (1996)

Impacts of Future C^4I System

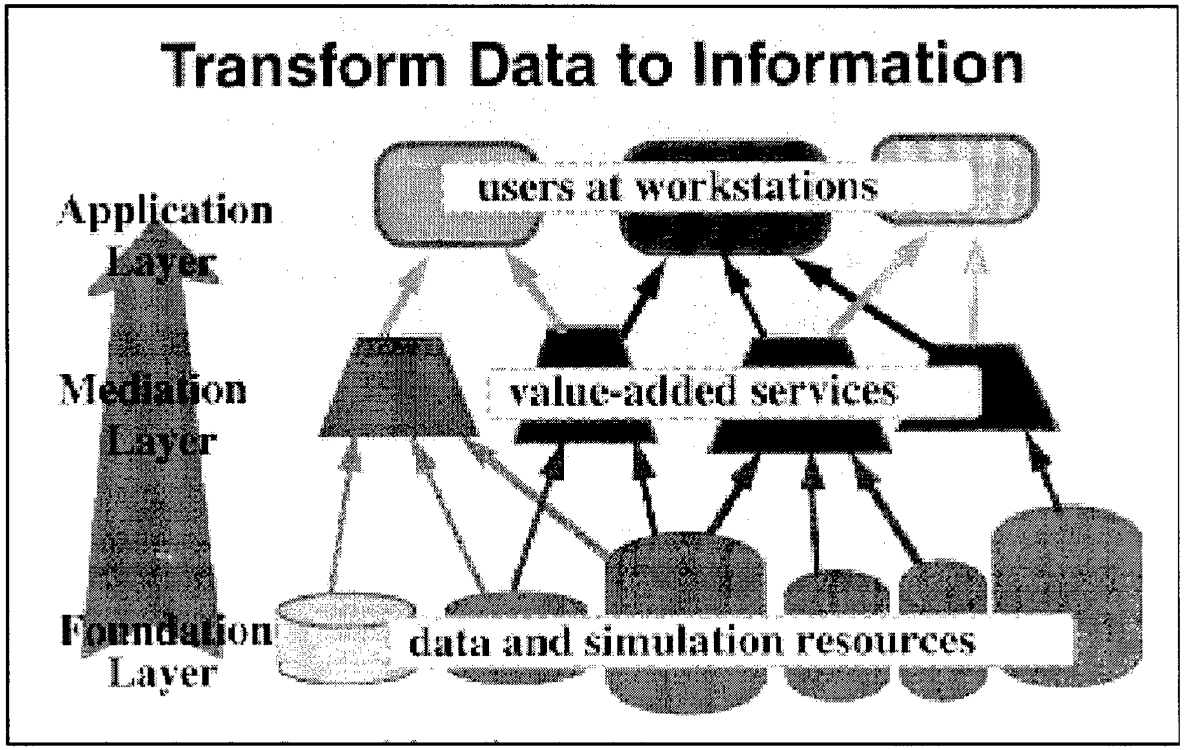
- Communication and decision-making more difficult due to
  - Geographical distribution of information sources, decision-makers, and field personnel
  - Cross-service and cross-cultural differences
  - Increased operational tempo
  - Vulnerability of underlying information grid
- Increased dependence on information technology to support decision making

Changes & Challenges

- More data
  - Need to *distill* information from data

OR

  - Cognitive workload will increase, and Situation/Battlespace Awareness will decrease



Graphic courtesy of Scientific Advisory Board (New World Vistas)

Changes & Challenges (con't.)

- More computerization
  - Improved information displays and virtual reality
  - Battle simulation and modeling
  - Information "blackouts" and alterations
- Increased OPTEMPO
  - Greater time pressure, mental workload, physical fatigue (*e.g.*, crew rest issues), and stress

Changes & Challenges (con't.)

- More distributed team communications and decision-making
  - Diverse, frequently changing team membership
  - New kinds of team communications and interactions
  - Pervasive system vulnerabilities
  - Need to *work around* problems resulting from system vulnerabilities

Insights from Team Performance Research

- *Taskwork* and *teamwork* skills are different
- *Team*work skills
  - Do not develop by placing skilled people together
  - Can be trained
  - Measurement is difficult

Insights from Team Decision-Making Research

- Experts teams are experienced teams (Orasanu, 1993)
  - Situation awareness
  - Planfulness
  - Shared mental models
  - Resource management
- Strategies used (Kanki, Lozito, & Foushee, 1989)
  - Shared mental models
  - Conventionalized, task-relevant conversation patterns

Insights from Team Decision-Making Research
(con't.)

- Advanced Team Decision-Making Model
  (Klein, Zsambok, & Thordsen, 1993)
  - Based on observing and training warfighters
  - Successful decision-making teams characterized by
    - Team identity
    - Team conceptual level
    - Team self-monitoring

Impact of Distance on Team Decision-Making

- Members bring different perspectives and resources
- Dependent on communication technologies
- Lose subtleties of interpersonal communication
- Requires task differentiation and distribution
- Increased management load

(Orasanu & Salas, 1993)

Impact of UAVs and IW on Personnel Requirements

- Skilled computer users
- Good team players, even at a distance
- System thinkers
- Decision-makers, flexible in coping with information blackouts and newly formed, multi-cultural groups

Potential MPT Research Areas

- Information, computerization, and job design
- Distributed/collaborative team formation, communication, and decision-making
- Rapid team building
- Methods to train and evaluate the above

Research Areas: Information, Computerization, and Job Design

- Information systems and displays
  - to *maximize*
    - System learning and retention
    - Ease of use and information access
    - Situation Awareness/Battlespace Awareness
  - to *optimize* mental workload
  - to *minimize* effects of system degradation
- Training and job aids to enhance team performance
- Screening to identify personnel who
    - Adapt well to distributed, information-based environment
    - Perform as effective team members

Research Areas: Distributed Team Communication and Decision-Making

- Facilitating rapid team formation and distributed communication
  - Race, gender
  - Language and culture (corporate and national)
- Team interaction, communication, situation awareness, and decision-making when
  - Technologies degraded
  - Information degraded/distorted
  - Technologies/information unavailable

Research Areas: Distributed Team Communication and Decision-Making (con't.)

- Training strategies
  - Initial training under optimal conditions
  - Performance under stress (*e.g.*, time pressure, noise, too little/too much information)
  - Sustainment training
- Metrics (MOPs and MOEs)
  - individual
  - group

Summary of Recommendations

- Basic MPT research concerning
  - team performance
  - distributed communication
  - distributed collaborative decision-making
- Training strategies to enhance
  - Team formation, interaction, and decision-making
  - Situation/Battlespace awareness
  - Communication skills
  - Diversity awareness

Conclusion

Resolution of HSI issues and MPT concerns is essential to realize the potential of the future C^4I system.

There are no unmanned systems.

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